Towards a Carbon Nanotube Ionization Source for Planetary Atmosphere Exploration

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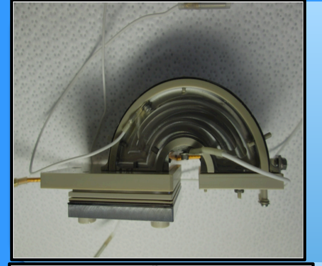
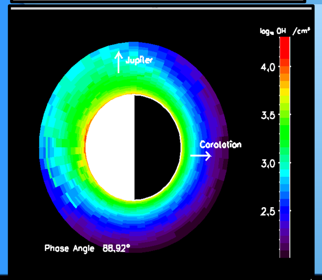


A Carbon Nanotube Electron Gun <CNTEG> is developed to ionize neutral atmospheres for future space spectrometry missions.



EGM simulations of Europa's Hydro-Exosphere show stark atmospheric structures dominated principally by Jupiter's gravitation.

Technology Objective

A carbon nanotube electron gun (CNTEG) is constructed for the highly sensitive exploration of exospheres, i.e. extremely tenuous atmospheres ($n < 10^8$ cm^{-3}). The CNTEG is based on the quantum principle of field emission[1] seeking to efficiently impact and therefore ionize diffuse neutrals known to be present around planetary bodies.

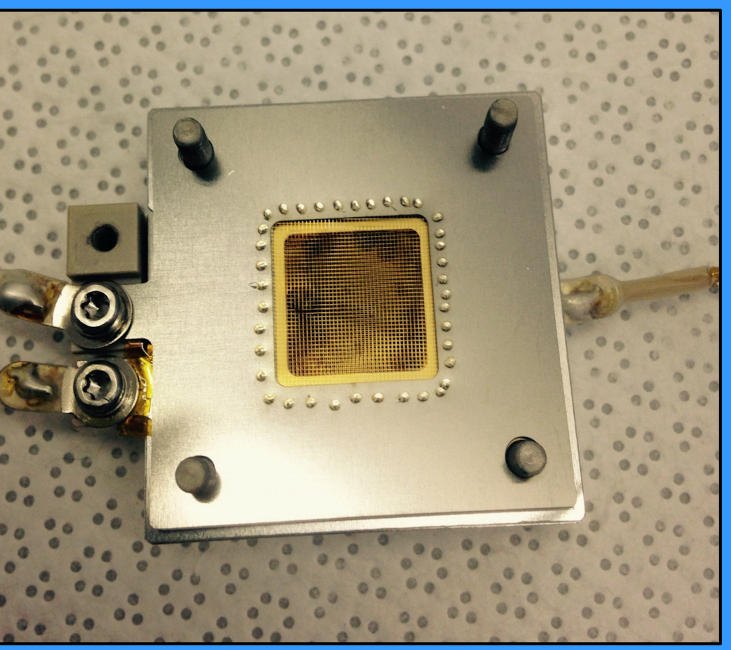
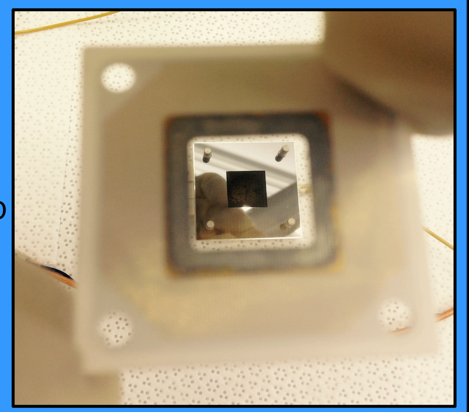


Fig. 1 CNTEG:
- Electric 'field effect emission' generates current due to solid-state quantum tunneling[1].
- Moderate E- field. (E ~1MV/m)
- Power-efficient. ($P < 0.1$ Watts)
- Sufficiently powerful current (I ~ 200 µA +/- 0.1 µA)
- Very stable. $dI/dt < 0.1$ µA/s
- Light-weight and robust.

Carbon Nanotubes as Cold Cathodes

Fig. 2 15 mm² CNT chip in the lens of the G1 grid grounded at +0V.



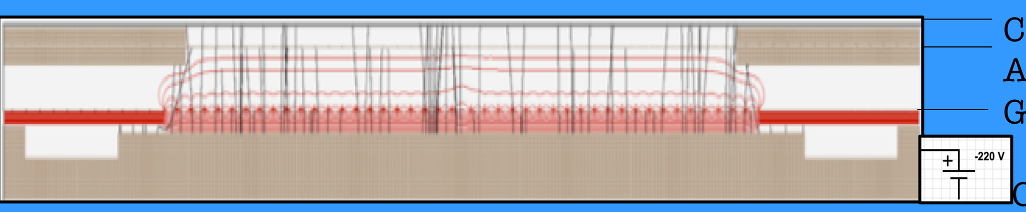


Fig.3 SIMION simulation of CNTEG electrodes' equipotentials and e⁻ trajectories. *Grids are at 80% transparency.

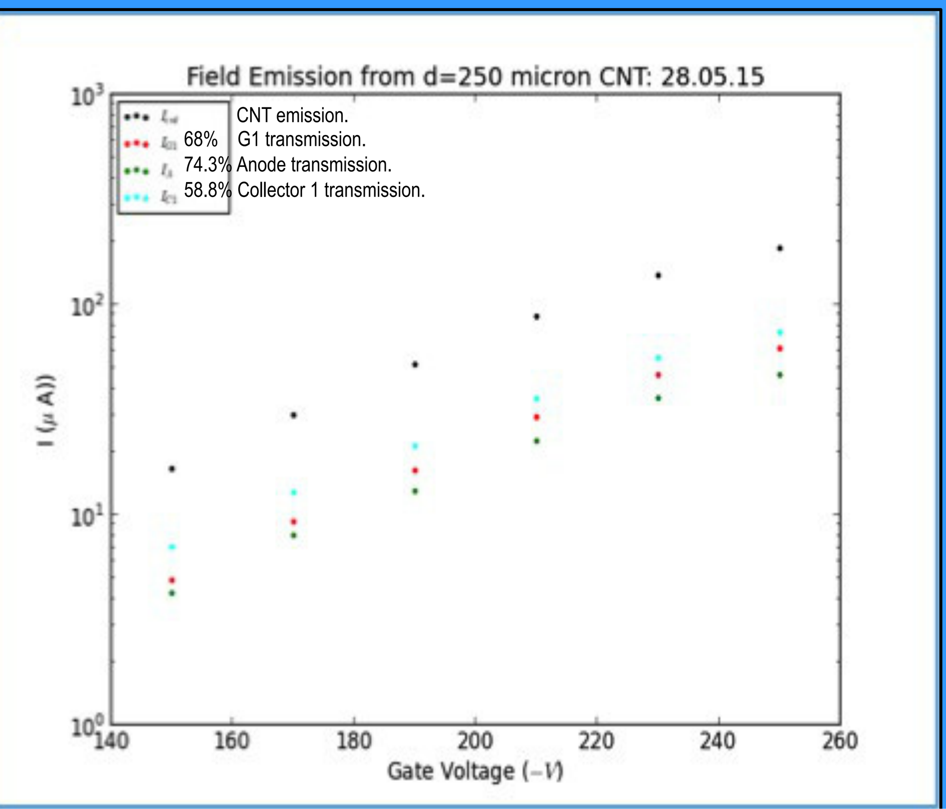
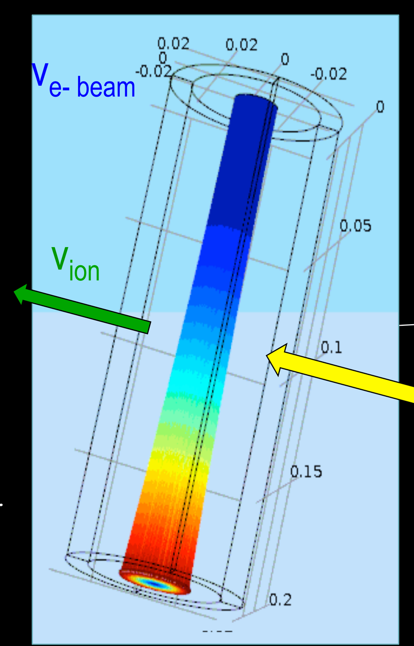


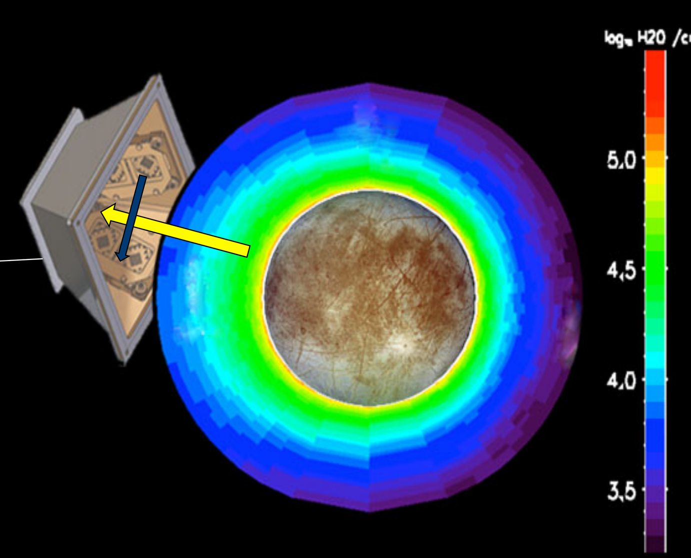
Fig. 4 : CNTEG electron field emission measured at each electrode labeled above.

- CNTEGs are emitting consistently at ~ 60% .
- Anode emission is at 75%.
- Emission > 100µA is achieved with a cathode-gate distance of d_{cg} = 250µm

Exosphere Ionization

Fig. 5: Selected COMSOL simulation of ionization volume demonstrating ion production via e⁻ impact.
--Box = 20 cm
--Beam width = cm
--J = 100 µA/cm²





Goal: To simulate & design ideal ionization geometry yielding maximum ion yield while taking space charge effects into account .

1)Electric force balance: $d/dt(m_e v_e)=qE$

2) Poisson's equation (space-charge):

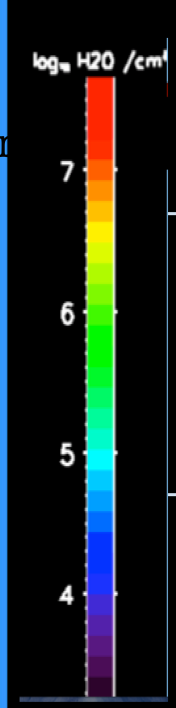
$\nabla^2\Phi=-\rho/\epsilon_0$

3)Electron-impact ion production rate:

$dn/dt=n_A * n_B \langle\sigma v\rangle_{AB}$

Europa's Hydro-Exosphere

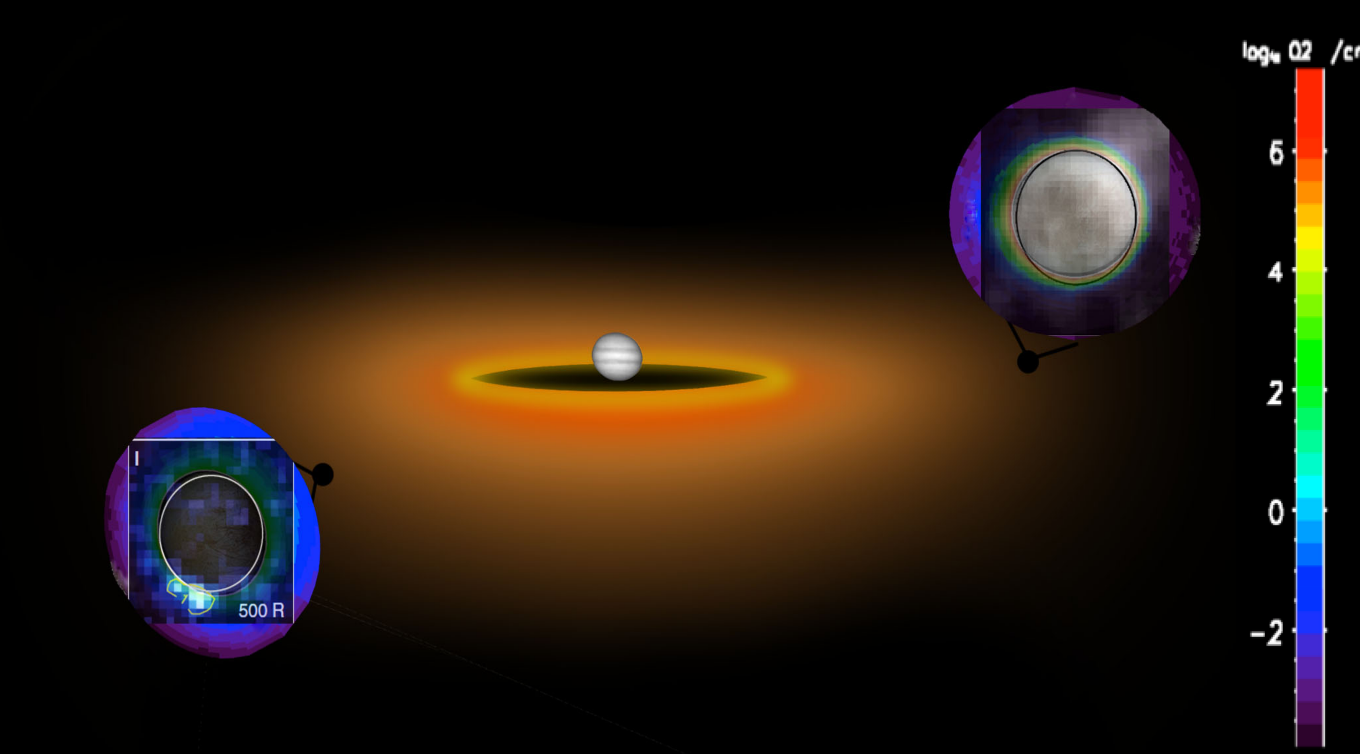
H20



Overall water exosphere is uniform in 1 ppt. HST detection[2] o excess H I Ly α, may be an anomaly.

Sub-Jovian water is more than 10x dense at high altitudes.

Slight H20 build-up at anti-jovian limb entering subsolar season.



O2

[Overlayed] HST observations[3] of O I have been associated to electron impact dissociation of O2.

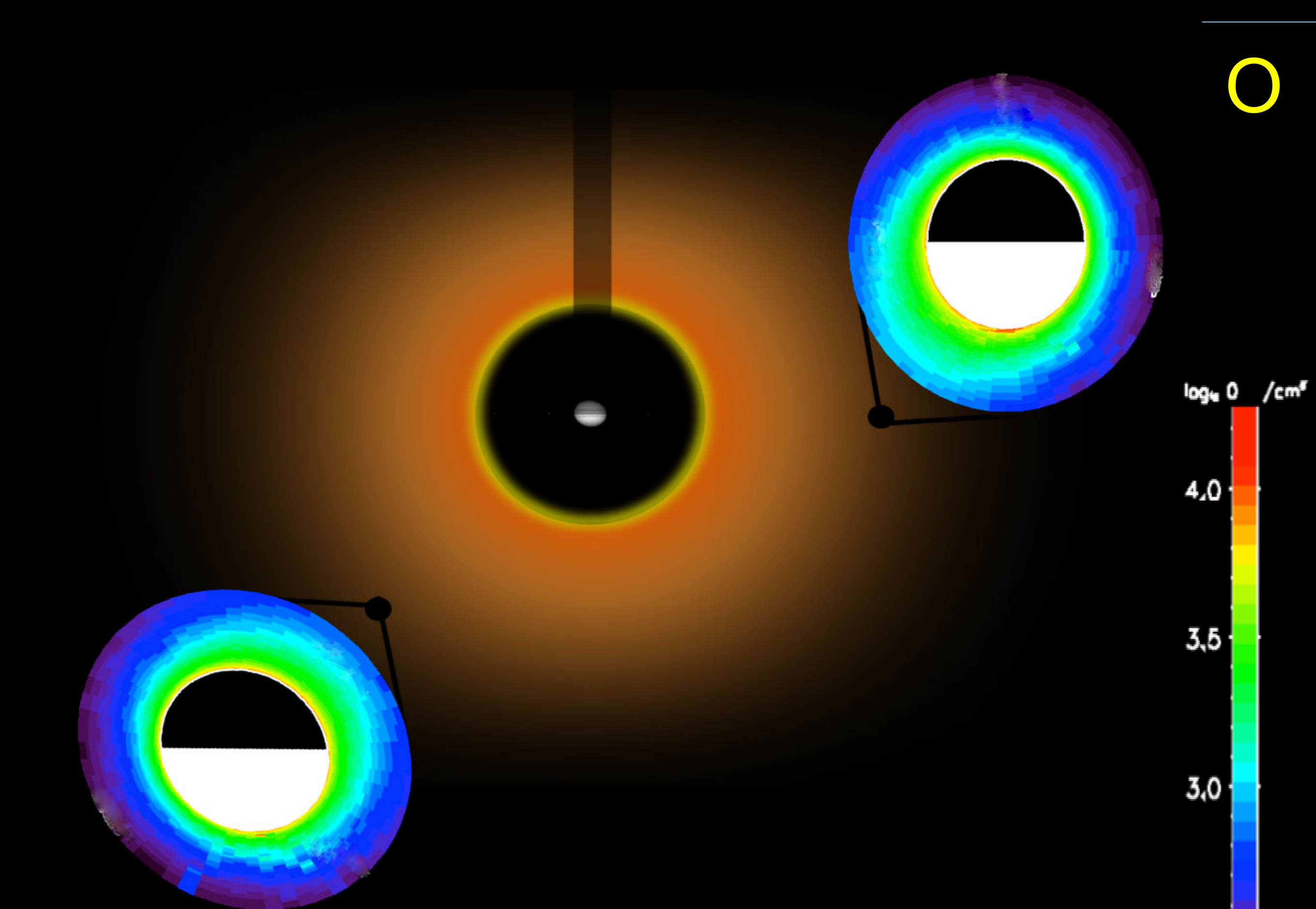
Sub-jovian O2 is > 1000 x more dense than the anti-jovian observations.

Jupiter is unique source of upper atmospheric O2. → Atomic O I more likely.

Fig.6: Side view of water (φ = 308°) & molecular oxygen (φ = 90°) simulation and observation.

a_g Atmospheric inhomogeneities due to Jovian gravitational field.

Upper exospheric oxygen behavior is identical to other water-products: H2, OH, H2O.



O Europa's hill sphere extends to about 8 R_{EU} beyond which Jovian gravity dominates.

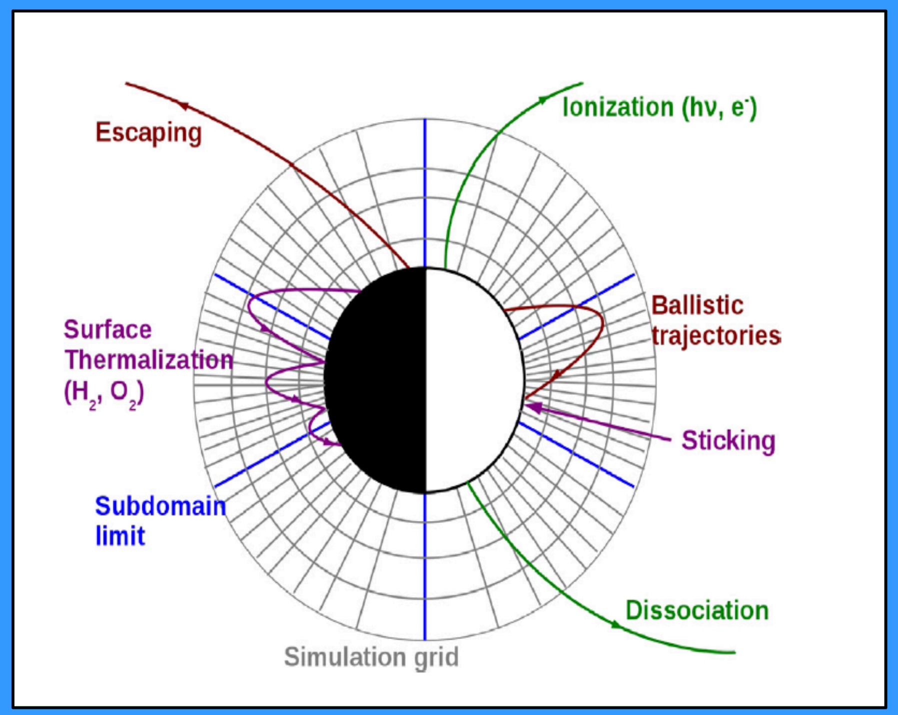
Day-night asymmetry is apparent. Effect is less for leading hemisphere as anti-solar is close to anti-jove.

Fig.7: Top view of simulated atomic oxygen exosphere.

Europa EGM

The Exospheric Global Model (EGM) is a 3D parallelized Monte Carlo code developed for the characterization of exospheres. Here, we model Europa. Test particles are ejected from Europa's surface up to ~ 15 R_{eu}, following known energy distributions. The test particles are on ballistic trajectories and can escape, stick, and bounce on the surface. Furthermore the particles can be dissociated/ionized by physicochemical processes.

Fig. 8: EGM domain modeling physical processes in spherical coordinates.



Results

Extended Exosphere Clouds are simulated, due to:

- Jovian gravitational drag is evident.
- Similar to sodium clouds at Io[5]
- Escape rates could indicate an Enceladus-like hydrotorus.

Perspectives from Surface-Exosphere inhomogeneities:
- Sputtering may not be global[9].
- O+, S+ ions may not dominate[6].
- Water-product escape rates match previous studies [7].
- O2 is thermalized to $T_{surface}$, speeds are not sufficient to populate upper exosphere.

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